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ILLUSTRATIONS

DAILY GROWTH OF THE OAT KERNEL AND EFFECT ON GERMINATION OF IMMATURITY AND CONTROLLED LOW TEMPERATURES[1]

ERNEST GORDON BOOTH

INTRODUCTION

The effect of temperatures of 32°F. (0°C.) or lower on the germination of oats before the crop has matured, is a question of economic importance with the northward expansion of the oat-growing area. Regions having climatic conditions favorable to the development of the oat plant frequently have early fall frosts. Even in less northerly latitudes, the oat crop, when of necessity sown late, is occasionally harvested in an immature condition after an early frost. Each year the seed laboratories test many samples of oats that are unfit for seed because of low viability. The cause of poor germination is uncertain, but it is frequently attributed to frost injury.

In a study of the effect of freezing temperatures on germination three conditioning factors are to be considered, as follows: The actual temperatures, the duration of the exposure to low temperatures, and the stage of kernel development. Without doubt each of these factors has a contributing or counterbalancing effect. Immaturity may be as important as temperatures at or below 32°F. (0°C.) in lowering the average germination.

It is also desirable to know the effect of low temperatures on different varieties of oats throughout the period of kernel development or any part of it.

In planning this investigation, consideration was given to each of these problems. The daily changes in the development of the oat kernel[2] were observed and an effort was made to determine whether any critical period existed when the injury from exposure to low temperatures might be severe. Oat kernels in different stages of development were exposed to controlled temperatures both above and below 32° F. (0°C.).

A study of the daily growth of the oat kernel should also throw some light upon the question of when to cut the crop to obtain maximum yield and quality. These factors are closely related to the time

[1] A thesis submitted to the faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of Doctor of Philosophy. Degree granted 1928.

[2] The term "kernel" is used to indicate the fertilized pistil during its development.

of harvesting and there is need for exact knowledge of the relationship existing between external and internal evidences of maturity.

Acknowledgments

The writer wishes to express his indebtedness to A. C. Arny, who suggested part of the study and helped to outline the work. Without his kindly constructive criticism and material aid, the study would not have been possible.

Thanks are also extended to W. A. DeLong and A. H. Larson, who rendered valuable service in making nitrogen determinations and germination tests.

REVIEW OF THE LITERATURE

The development of wheat and barley kernels has been studied by European investigators, but these studies were prompted by a desire to learn more about the development of protein and starch in the caryopsis. Besides working with a different object in view, the climatic conditions under which the work was accomplished were very different, the growing season being much longer and the precipitation greater. As a result, the work of early European investigators apparently has little bearing upon the present problem.

Johannsen (1884) studied the development of the barley kernel at three-day intervals. His work included a careful chemical and cytological study of development from blossoming time to maturity. Starch grains appeared very early in the development of the kernel.

Schjerning (1906, 1914) made a detailed study of the protein at different stages of maturity in several varieties of barley. He concluded that environment was more effective than variety in determining the total nitrogen content. In his studies, the growing period was divided into two stages—developmental and ripening. To quote his conclusions is illustrative. "At the close of the developmental period the barley grain has reached its maximum volume, at the end of the ripening period its highest amount of dry matter. At the moment when the grain has reached the stage of full maturity we have (allowance being made for analytical errors) reached the maximum values for dry matter, ash, acid, and total insoluble nitrogen." Overripening caused loss of these materials. "Yellow ripeness" was his measure of maturity.

Brenchley (1912) and Brenchley and Hall (1909) studied the development of barley and wheat at three-day intervals. In barley, nitrogen and ash increased steadily until ripening began. Nitrogen then increased and ash decreased. The dry weight increased uniformly during the developmental stage. During this period, the water content

of the kernels in both crops was also similar. The nitrogen content varied slightly in different stages. Brenchley concluded that the progressive changes in the two grains are parallel, tho varying in detail. The prolonged ripening period of barley, during which maturation changes occurred, was held to be the chief difference. A comparison of the changes in the cell in both wheat and barley showed the course of the phenomena to be exactly similar. The cells in the flanks showed the first infiltration of starch and disorganization of the protoplasm. The sub-aleurone and furrow cells showed the last changes.

Thatcher (1913, 1915) harvested spikes of three varieties of spring wheat at three-day intervals. The spikes were tagged when the largest proportion of them showed anthers protruding from the central spikelets. The percentage of protein in the dry matter decreased slightly until the milk stage, then increased to maturity. The mature samples contained more protein than the very immature ones. The actual quantity of each material except sugars increased with each period of harvest. The carbohydrate-protein ratio diminished with the successive harvests.

Kedzie (1880, 1881, 1893), as early as 1879, working in Michigan, studied the daily development of the wheat kernel. Measurable growth occurred in each twenty-four hour period. Just after flowering, the ash content was 4.72 per cent of the dry matter. When the first starch grains appeared, on the seventh day, the percentage of ash was reduced to 3.42, and on the twenty-seventh day, when the kernels were becoming hard and flinty, it was 2.13. The crude protein content for the same days was 36.22, 22.76, and 11.69 per cent, respectively.

The daily increment of dry matter was rapid and, in effect, a straight line increase until about the twelfth day. From this period until near maturity the increase in dry matter was slow. A loss was noticeable after the kernels were hard.

Harlan (1920) studied the kernel development of Hannchen barley. He made daily physical measurements at twelve-hour intervals. Measurable growth occurred during these periods. Development was very rapid just after pollination and length growth was completed by the seventh day. The increase in width then became rapid for a short time. The kernel continued to increase in thickness steadily until near maturity. The increase in dry matter and the decrease in the percentage of water were uniform until the kernels were ripe. The ash content varied from 8.96 per cent of the dry matter during the first few days to less than 2 per cent when the grain was mature. There was a variation in nitrogen from 4.45 per cent of the dry matter to about 2 per cent in the same direction as the ash.

The same author (1923) found that the laying down of dry matter ceased when the average moisture content for all the kernels of a spike was about 42 per cent. There was also a decrease in physical measurements toward the end of the maturation period.

Dillman (1928) studied the daily development of flax seeds. Daily physical measurements were recorded and samples were analyzed to determine when the oil was laid down. Growth was rapid and uniform up to the thirteenth day, when maximum size was attained. All three dimensions increased during this time. During the ripening period there was a decrease in size. The green weight also approached its maximum in the same period but, unlike the cereals, did not begin to decrease until after the twenty-second day. The increase in dry weight was slow during the first few days, then slightly more rapid and uniform until the end of the developmental period. The moisture percentage started at 85 and did not begin to decrease until after the eighth day. The decline was then uniform.

Oil first appeared between the fourth and sixth days. The quantity increased rapidly until the eighteenth day, then slowly until the thirtieth day. The amount of oil increased after the percentage was stationary.

The developmental period extended over about thirty days, but the flax was not considered ripe until the thirty-ninth or fortieth day after pollination.

Controlled experiments to determine the effect of temperatures of 32°F. (0°C.) or lower upon germination have been difficult to perform until recent years. The lack of suitable laboratory equipment and the uncertainty of climatic conditions favoring such experiments have limited the number of attempts to study the effect of frost injury on germination. Fryer (1919) planted oats at weekly intervals in the spring to obtain samples in different stages of maturity at the time frosts occurred in the fall. He found that 2.3 degrees, 29.7°F. (−1.3°C.) of frost (presumably Fahrenheit degrees) did not reduce the vitality of samples ranging in development from very early milk to dough. Similarly, 4.6 degrees, 27.4°F. (−2.6°C.), did not injure samples in the milk stage to the mealy dry stage. Samples in the dough to the mealy dry stage were not injured by 5 to 8 degrees, 27° to 24°F. (−2.7° to −4.4°C.), but those in milk to dough stages were considered injured. The twelve-day germination of the latter group was reported as 76 to 92 per cent before freezing and three days later after two frosts, one of 5 degrees, 27°F. (−2.7°C.) and the other of 8 degrees, 24°F. (−4.4°C.), the germination ranged from 45 to 61 per cent. The duration of the temperatures of 32°F. or below, the dry matter content, and the number of samples averaged

to obtain each germination report were not given. Registered Banner oats were used in the experiment. In most cases the very immature samples had a slightly lower germination than the more mature samples. This was apparently not consistent enough, or of a sufficient degree, to be commented upon by the author. The same author (1921) at a later time planted oats at different periods in the spring and succeeded in getting two samples in the late dough stage frozen at different temperatures. One sample was subjected to a temperature of 23.5° F. (—4.8° C.) and the other to the same temperature and also to temperatures of 19° F. (—7.2° C.) and 30° F. (—1.1° C.) on succeeding nights. The duration of the periods at these temperatures was not given or any of the details regarding the germination tests. The final germination of these samples was reported as follows: check, not frosted, 97 per cent; 23.5° F. (—4.8° C.), 81 per cent; 23.5° F. (—4.7° C.), 19° F. (—7.2° C.) and 30° F. (—1.1° C.), 61 per cent. He found that freezing tended to fix the greenish color, particularly at the germ end, if the oats were very immature. Presumably this refers to the remaining floral parts, including the lemma and palea. Brittleness was increased and the interior of the endosperm was frequently darkened as well as the strand of tissue that traverses the bottom of the groove.

Johnson and Whitcomb (1927) reported that immature wheat kernels were injured by temperatures of 32°F. (0°C.) or below. The effect of immaturity was apparently not included in the study. Both field frosts and a controlled temperature of 27° F. (—2.7° C.) for twenty-four hours were included in the tests. With these temperatures, there was enough injury in a few samples to reduce the germination materially. They found germination of four frosted samples to be decidedly lower in the field than in the laboratory.

Kiesselbach and Ratcliff (1920) found that freezing immature or moist corn discolored the embryo. When the moisture content was above normal, the germination was injured in proportion to the percentage of moisture and the duration of the frost.

In recent years there has been a tendency to question whether the laboratory test is an adequate gauge of the field germination. Whitcomb (1924) found that over a four-year period the field germination of 164 samples of oats averaged 15 per cent less than the most favorable laboratory germination. The average germination of 641 samples of wheat was 20 per cent lower in the field. Ten kinds of agricultural seeds were included in this test and 1,298 samples were germinated during the four years, in both the laboratory and the field. The average germination was 24 per cent lower in the field than in the laboratory. It is interesting to note that in three out of four years field peas germinated at a higher rate in the field.

Wright (1921) found that oats germinating between 70 and 100 per cent in the laboratory showed an average of 10 per cent less in the field. When the laboratory germination was below 65 per cent, the field germination averaged 21 per cent lower. Other field-crop seeds showed a similar tendency. The difference between laboratory and field germination tests was more pronounced with the smaller seeds.

Several investigators have noticed the lack of vigor in young plants produced from seeds that were harvested before they were normally ripe. Crozier (1895) germinated wheat harvested in the milk, dough, yellow ripe, and dead ripe stages. The seeds harvested in the milk stage germinated the most rapidly. These seedlings were feeble and pale and were soon passed in growth by those from more mature seeds. Seeds harvested in the yellow ripe stage germinated most vigorously. Harlan (1922, 1926) found that barley kernels harvested five and six days after pollination would germinate. The seedlings were much less vigorous and, when transplanted, produced plants that were less robust than those from mature kernels. Methods of drying the immature seeds materially affected the development of both the endosperm and the embryo. When the kernels remained in the spike and it was not allowed to become dry, the endosperm and the embryo continued to develop for at least eight days. There was less development when the kernels were air-dried in the lemma and palea, whether they remained in the head or were detached. The embryos of immature kernels from which the lemma and palea had been removed did not develop further unless the kernels were kept moist.

Alberts (1926) obtained weak plants on germinating corn harvested in an early stage of development. Seeds gathered in the milk stage germinated poorly and showed weak sprouts. When harvested in the late milk stage there was a decided improvement, but the germination was still unsatisfactory and the seedlings were weak. Seeds harvested in the dough stage germinated satisfactorily and produced strong seedlings.

Kiesselbach and Ratcliff (1920) found that delaying the harvesting of corn until the kernels reached the late dough stage increased the percentage of germination.

PROGRESSIVE DEVELOPMENT OF THE OAT KERNEL

It seemed logical in attacking the problem in hand to study the development of the oat kernel first. With this information in mind, it should be easier to interpret the results obtained in later studies.

Materials and Methods

Gopher oats, Minnesota No. 674, developed and grown at University Farm, St. Paul, was used for the study. A typical panicle of this early, high yielding variety of white oats is shown on the left in Figure 1.

The seed for the experiment was planted with the grain drill on one of the regular experimental plots on April 20, 1926. The soil is classified as Hempstead silt loam and consists of black loam underlaid with a small amount of clay which merges into sand and gravel at 8 to 10 feet.

Fig. 1. Panicles of Gopher Oats
Left. Typical Panicle
Right. Panicle of Gopher Oats with the Spikelets Discarded in the Daily Studies Removed

The spring and early summer were unusually dry, with practically no rainfall during April, May, and the first ten days of June. A comparison of the precipitation and temperature during this period with past averages is included in Table I. While the precipitation was much less, the mean temperature did not vary greatly from the long-time average for the respective months.

As a result of the lack of moisture during early growth, the oats headed out with shorter straw than usual, the height being 24 inches as compared to the usual length of about 30 inches. The yield was 34.1 bushels as compared to the seven-year average of 58.5 bushels per acre. Timely rains in June caused normal growth and filling of

the kernels from before heading until harvest. Despite adverse conditions during early growth, the stand was fairly uniform at heading time.

TABLE I

DAILY WEATHER OBSERVATIONS DURING KERNEL DEVELOPMENT, JUNE 29 TO JULY 24, AND MONTHLY AVERAGES, AT ST. PAUL, 1926

Date	Precipitation, in.	Maximum temperature, ° F.	a.m.	p.m.
June 29	...	85	Cool and cloudy	Clear
30	...	80	Cool	Cool
July 1	0.56	73	Rain, clouds	Cloudy, sultry
2	T	79	Cloudy, cool	Cloudy, sultry
3	...	82	Clear, cool	Clear, warm
4	0.06	79	Cloudy, cool	Cloudy, showers
5	...	82	Clear, warm	Clear, warm
6	...	88	Clear, warm	Clear, hot
7	...	86	Clear, warm	Clear, hot
8	T	90	Cloudy	Clear, sultry
9	0.25	78	Cloudy, cool	Cloudy, cool
10	...	73	Clear, cold	Cloudy, cool
11	T	80	Clear, cool	Cloudy, cool
12	...	68	Clear, cool	Clear, cool
13	...	73	Clear, cool	Clear, cool
14	...	77	Clear, warm	Clear, cool
15	T	85	Cool	Hot, high wind
16	...	98	Clear, warm	Clear, hot, breezy
17	...	86	Clear, warm	Clear, warm
18	T	94	Clear, cool	Clear, hot, breezy
19	0.03	89	Cloudy, sultry	Clear, hot
20	0.47	99	Cloudy, sultry	Clear, sultry
21	0.41	73	Cloudy, cool	Clear, cool
22	0.02	79	Clear, warm	Cloudy, cool
23	0.15	73	Cloudy, cool	.....
24	0.26	69	Cloudy, warm	.....

	Precipitation				Maximum temperature, ° F.				
	April	May	June	July	April	May	June	July	
Total	0.53	1.37	3.65	2.92	43.8	61.4	63.7	71	Mean
Normal	2.33	3.62	4.41	3.40	45.6	56.4	67.1	72.	Normal

The first heading occurred on June 27 and apical spikelets were visible on about one per cent of the panicles on June 29, when the first tagging was done. By previous observation it was determined that the florets of the apical spikelets in different panicles were at a uniform stage of development when first appearing out of the sheath. Accordingly, this was taken as a basic stage in development and several hundred such panicles were tagged on June 29. Panicles in the same stage of development were tagged on June 30, July 2 and 3. The tagging was done with short lengths of colored yarn to distinguish between the plants that represented twenty-four-hour periods in development. More than eight hundred panicles were tagged for the study.

Observations on oats sown at an earlier date in the same year indicated that there was a considerable lapse of time between the

pollination of the upper and lower spikelets in the panicle. To obtain a group of kernels that were in a similar stage of development in the same panicle it was necessary to remove the apical spikelet and all the spikelets of the lower whorl. In addition, the spikelet with the shortest pedicel in the middle whorl was removed, as shown in Figure 1. The secondary floret in each spikelet was later in fertilizing than the primary floret and a further distinction was made by using only primary florets.

As soon as general pollination of the florets used in this study had taken place, samples were gathered from different parts of the plot each morning at about seven o'clock. The tagged plants were pulled with the roots attached and were wrapped in a damp cloth before they were removed from the field. The first operation in the laboratory was to remove the overmature and undermature kernels, as illustrated on the right in Figure 1 and previously discussed.

The sample gathered each day was divided into two portions. One part was used to determine the physical measurements, dry matter, and ash. This sample consisted of twenty kernels selected from three or four panicles. To minimize drying after removing the flowering glumes, with a consequent change in size, the work was done rapidly. In each case groups of five kernels were used. In the regular procedure the hulls from one group were quickly removed and the kernels placed on a glass slide. By drawing the glass under the lens of a high-power binocular fitted with a measuring eye-piece, the length and width could be recorded at once. The kernels were then placed on edge with a dissecting needle to determine the thickness. Measureing the four groups required about twenty minutes, and as soon as the measuring of each group was completed, the kernels were placed in a covered weighing bottle. The green weight of the twenty kernels was next determined, and immediately afterward the sample was placed in a drying oven for twenty-four hours at 204.8°F. (96°C.). After weighing and checking the dry weight, the same twenty kernels were used in determining the ash content.

The other part of the sample gathered each day was set aside to be used in determining the nitrogen content. To obtain a large enough sample for chemical analysis, it was necessary to use six panicles. The spikelets were stripped from these panicles and dried for one hour at 204.8°F. (96°C.). The daily samples were then placed in paper envelopes and stored in a metal box until analyzed.

Daily weather observations were made from June 29 to July 24. During this period, the precipitation was slightly below normal. There were several heavy rains and periods of intense heat. Responses to these occurrences could be readily noted in the daily studies.

Table I indicates that during July, when daily samples were being gathered, the total precipitation was 2.92 inches. The average July precipitation for several years is 3.40 inches. The mean temperature for the month was 71.8°F. (22.1°C.) as compared to a past average of 72.1°F. (22.3°C.). These records indicate that the weather during July was nearly representative.

Confusion exists in the literature as to the meaning of such terms as "developmental period," "maturity," and "ripe." In this paper, the first term is used to designate the period during which rapid growth changes are taking place in the kernel. Following the developmental stage, there is a period of ripening. The term "mature" is used to indicate the time at which harvesting would ordinarily take place. Such expressions as "ripe" and "yellow ripe" are used with the same meaning as the word "mature" and mean the accepted time of harvesting as previously expressed. In the discussion that follows, the term "width" has been used to express the lateral measurement of the kernel; the word "thickness," to designate the dorso-ventral measurement. There is also frequent reference to pollination in the floret. When the anther sacs become ripe they break open and deposit pollen on the stigmatic surfaces. The time during which the pollen is deposited is referred to as the period of pollination.

Detailed Study of Pollination in Florets of the Same Panicle

The difference in time of pollination within the panicle observed while examining oats seeded at an earlier date prompted a more complete study of pollination by using some of the tagged plants. Observations on the panicles tagged June 29 showed that during the first day from three to five of the spikelets emerged from the boot. The stamens, style branches, and ovaries in all these spikelets were very immature, being greatly compressed and firm. The next day the panicles were about two-thirds emerged from the boot and the apical primary floret had pollinated. A few withered anthers were also visible, indicating that the lemma and palea had opened slightly. On July 1 the panicles were just clear of the sheath. The weather turned cool at this time and apparently little or no further change occurred until July 3, when the majority of the florets shown in the panicle on the right in Figure 1 pollinated.

Pollination in the florets could be detected by the behavior of the style branches. Within a few hours after the pollen was deposited upon the stigmatic surfaces, the style branches curved inward at the apex. The stigmatic surfaces were, therefore, soon pressed firmly together, as indicated in Figure 2. For convenience in identification, those in the vertical series in Figure 2 have been numbered 1 to 5, and those in the horizontal series 6 to 11, inclusive. At the intersec-

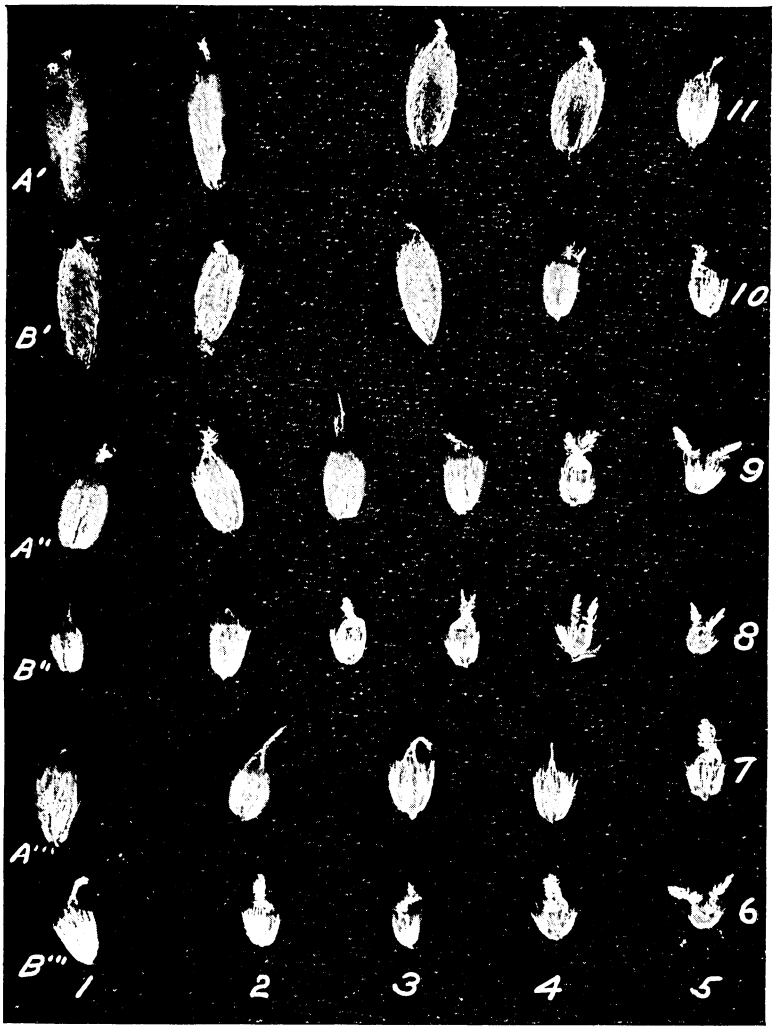

Fig. 2. Relative Stages of Development in the Same Panicle

The photograph was taken three days after general pollination of florets in the upper and middle whorls. The kernels from a complete panicle, as shown on the left in Figure 1, are included in this illustration. The series marked A are primary kernels and those marked B are the secondary kernels from the same spikelet. Starting at the upper left-hand corner and reading from left to right, the series A', A'', A''' represent the order of arrangement of kernels in the panicle from the apex downward.

tion point of vertical series 4 and horizontal series 8, two styles are just converging. The pistil immediately above it, 4-9, was pollinated some hours earlier, and the stigmatic surfaces are pressed past each other; 5-9 is still unpollinated. About twenty-four hours after pollination the style branches withered slightly, as shown in 5-10, and were dry and brown at forty-eight hours, as shown in 3-7 and 4-7. These

photographs show clearly that pollination took place in the secondary florets twenty-four to seventy-two hours later than in the primary florets. This can be observed by referring to specific primary florets and the secondary florets of the same spikelets. In Figure 2 kernel 5-10 is the secondary and 5-11 the primary kernel in the same spikelet with 5-10 about forty-eight hours behind 5-11. Kernel 2-6 is also about forty-eight hours behind its primary kernel 2-7.

The first pollination in the apical spikelets occurred on June 30. Pollination of the florets in the lower whorl began on July 4 and the process continued progressively downward until July 8, when it was complete. Pollination, therefore, extended over a period of eight days. Harlan (1926) observed that barley florets located in the middle of the spike were the first to pollinate. Later pollination occurred in both directions from the middle.

Figure 2 illustrates the range of maturity in a representative panicle three days after pollination of the florets giving rise to the kernels used in this study, and in Figure 3 is brought out the range of maturity of the kernels in another representative panicle at nine days. In Figure 2 kernel 1-11, which was produced by the apical primary floret, is nearly full length; the stigmatic surfaces of 5-6, a secondary floret, in the lower whorl, have not been pollinated. The relative uniformity of the kernels used in this study during their early development is also illustrated in Figures 2 and 3. In Figure 2 kernels 2-11, 3-11, 4-11, 5-11, 1-9, and 2-9 represent the group studied. In Figure 3, the kernels included in this group are numbered 2-11, 3-11, 4-11, 1-9, and 2-9. Altho there is considerable difference in length, the withered style branches attached to the kernels mentioned, particularly those in Figure 2, indicate that the florets were pollinated at approximately the same time. The uneven development in length was not very noticeable after the first few days.

Changes in Physical Measurements

The length, width, and thickness of the twenty kernels from which the hulls had been removed were each averaged and are reported in Table II.

Length.—The length measurements given in Table II show the daily range in twenty kernels. These differences are considerable and may be due to time of pollination or growth rate. After the early rapid growth period, there was a tendency to smooth out these irregularities.

During the first six days there was a rapid increase in length, the kernels developing 82.3 per cent of the maximum length reached on the fifteenth day. The mean length increased slowly from the sixth to the fifteenth day, but many of the kernels had reached full length by the tenth and eleventh days.

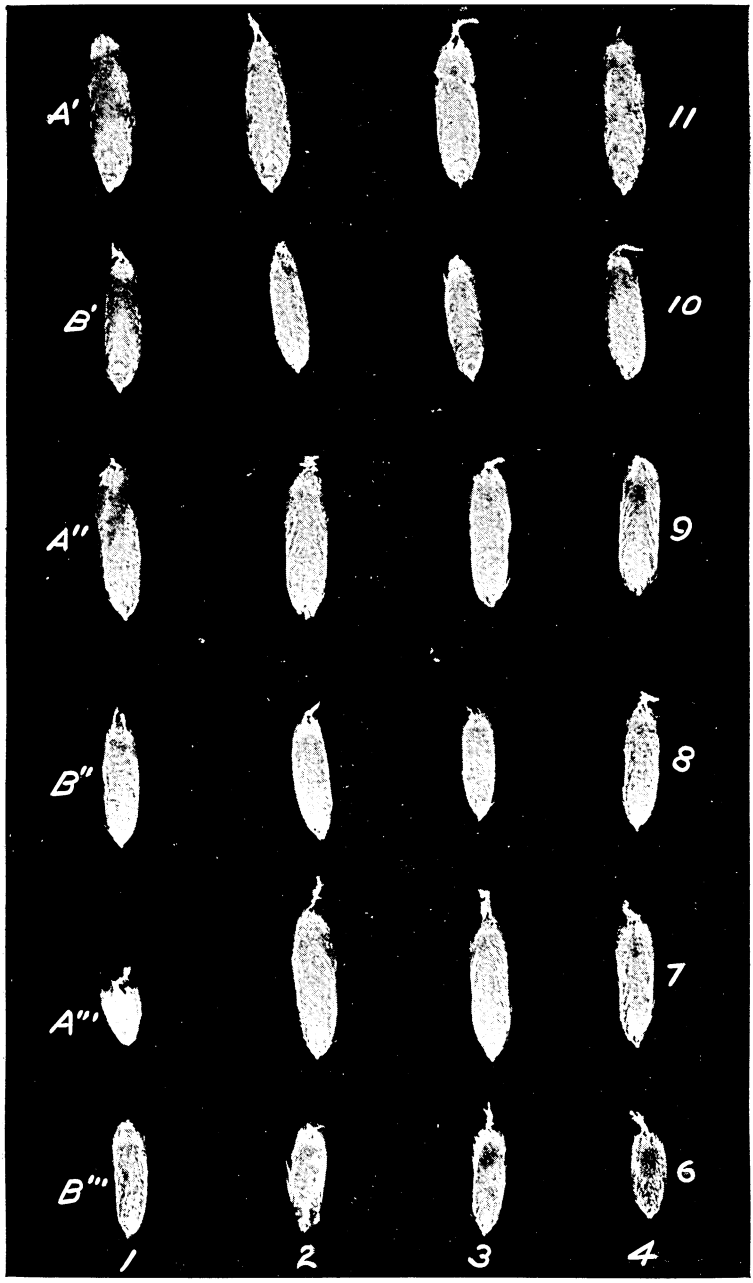

Fig. 3. Relative Stages of Development in the Same Panicle

The photograph was taken nine days after general pollination of the kernels in the upper and middle whorls. The kernels from a complete panicle, as shown on the left in Figure 1, are included in this illustration. The series marked A are from primary florets and those marked B are the secondary florets from the same spikelet. Starting at the upper left-hand corner and reading from left to right, the series A', A'', A''' represent the order of arrangement of kernels in the panicle from the apex downward.

TABLE II

DAILY MEASUREMENTS OF LENGTH, WIDTH, AND THICKNESS OF GOPHER OAT KERNELS

Date	Days after pollination	Determinations on 20 primary kernels with the hulls removed									Stage in development
		Length			Width			Thickness			
		Average	Range	Per cent of maximum	Average	Range	Per cent of maximum	Average	Range	Per cent of maximum	
		mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	
July 4	1	1.89	1.3- 2.6	20.6	2.03	1.5-2.2	69.5	1.62	1.3-2.0	64.5	
5	2	2.60	1.5- 4.1	28.3	2.17	1.9-2.6	74.3	1.83	1.6-2.0	73.3	
6	3	4.47	2.8- 7.5	48.7	2.51	2.1-2.7	85.9	1.92	1.7-2.2	76.4	
7	4	5.80	3.9- 8.3	63.2	2.60	2.3-2.9	89.0	2.06	1.8-2.3	82.0	
8	5	6.25	3.3- 8.7	68.1	2.66	2.3-2.8	91.0	1.99	1.8-2.1	79.2	
9	6	7.55	5.8- 9.0	82.3	2.66	2.4-3.0	91.0	2.10	1.9-2.3	83.6	Early milk
10	7	7.64	6.8- 8.8	83.3	2.64	2.5-2.9	90.4	2.18	1.9-2.5	86.8	
11	8	8.24	7.8- 9.1	89.8	2.73	2.5-3.0	93.4	2.26	2.1-2.4	90.0	First yellow color
12	9	8.47	7.8- 9.1	92.3	2.81	2.6-3.0	96.2	2.38	2.3-2 6	94.8	Late milk
13	10	8.64	8.0- 9.7	94.2	2.85	2.6-3.0	97.6	2.42	2.2-2.7	96.4	General yellow color
14	11	8.84	8.3- 9.4	96.4	2.91	2.6-3.1	99.6	2.46	2.2-2.7	98.0	Early dough
15	12	8.81	8.0- 9.5	96.0	2.92	2.7-3.1	100.0	2.45	2.3-2.7	97.6	
16	13	9.01	8.0- 9.6	98.2	2.87	2.6-3.1	98.2	2.51	2.1-2.7	100.0	Dough
17	14	9.06	8.0- 9.8	98.8	2.64	2.1-2.9	90.4	2.31	2.0-2.6	92.0	
18	15	9.17	8.3-10.0	100.0	2.76	2.3-3.2	94.5	2.39	2.0-2.7	95.2	First ripe
19	16	8.86	8.1- 9.5	96.6	2.56	2.1-2.9	87.6	2.24	1.8-2.6	89.2	
20	17	8.79	8.3- 9.3	95.8	2.53	2.2-2.9	86.6	2.16	1.8-2.5	86.0	General ripe
21	18	8.89	8.4- 9.3	96.9	2.31	2.1-2.6	79.1	1.98	1.8-2.2	78.8	
22	19	8.84	8.5- 9.3	96.4	2.43	2.1-2.7	83.2	2.06	2.0-2.2	82.0	
24	20	8.70	8.1- 9.1	94.8	2.25	2.0-2.5	77.0	1.93	1.8-2.2	76.0	
24	21	8.66	8.0- 9.6	94.4	2.26	2.0-2.2	77.3	1.94	1.8-2.1	77.3	

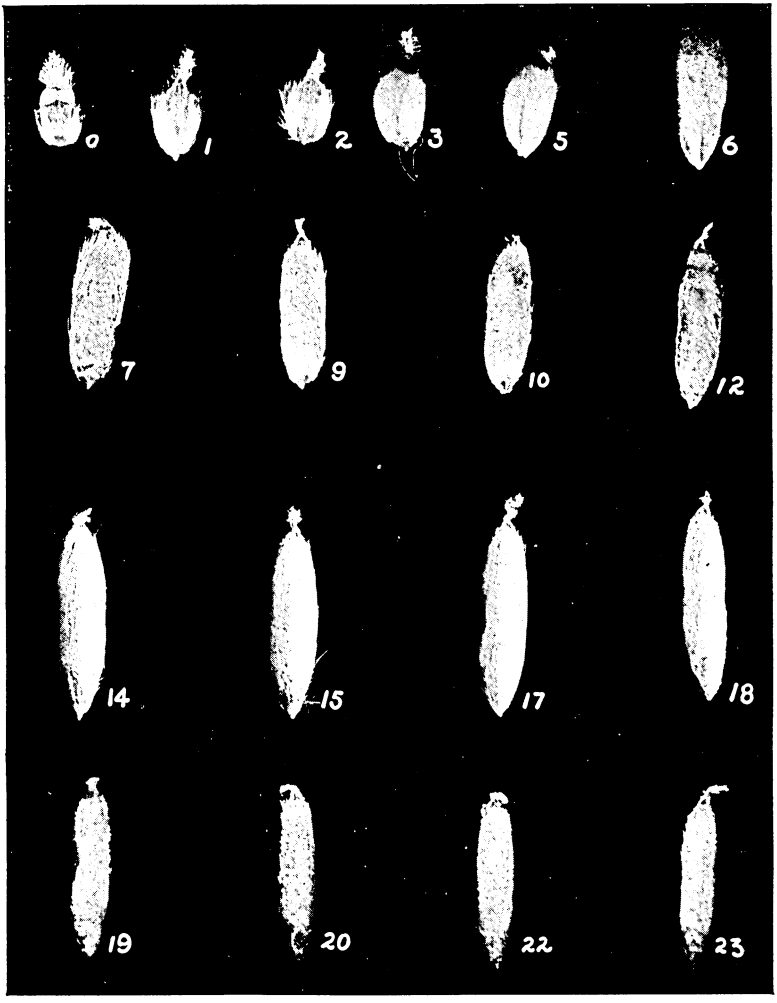

Fig. 4. Appearance of Kernels During Development
The number indicates the days after pollination.

Maximum development in length was reached on the fifteenth day and thereafter there was a tendency to decrease in length as the percentage of dry matter increased and ripening progressed. In the last sample harvested the kernels averaged only 94.4 per cent of the maximum length. The rapid falling away in length between the fifteenth and sixteenth days was due to extreme desiccation caused by three very warm days preceding this date. There was a tendency to reestablish the length after rains, which occurred on three days following the warm weather.

The mean daily increase in length as shown in Table II is presented graphically in Figure 5.

Width and thickness.—In the early stages of development, the germ end of the kernel was partly obscured by a dense growth of fine hairs (Fig. 4, kernels 1, 2, and 3). This did not interfere with measuring the length, but the width and thickness could be measured during the first few days only by including the hairs. After the second or third day this difficulty did not exist, because the growth in length spread the hairs over a greater area, making the surface visible. All measurements were made at the widest point. During early

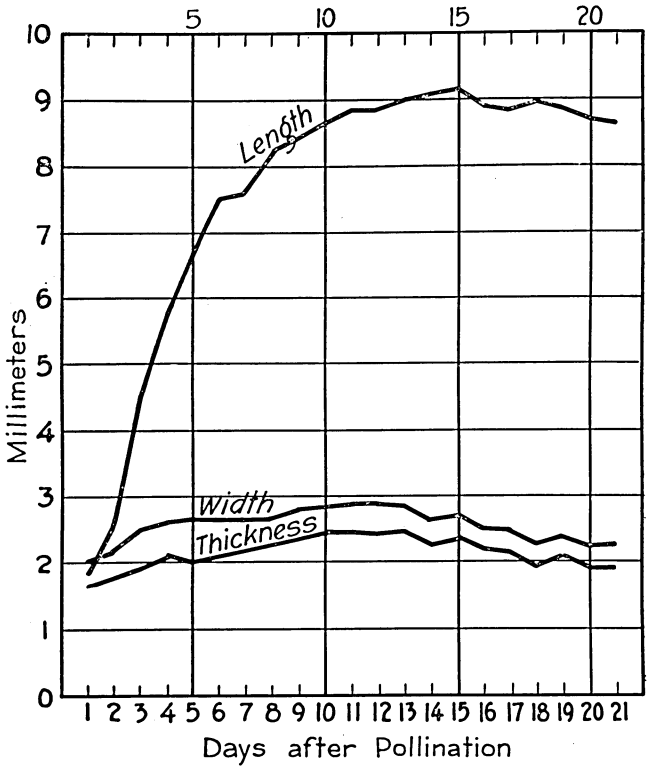

Fig. 5. Daily Growth Change in Length, Width, and Thickness from the Day After Pollination Until Maturity

growth, the brush end was somewhat truncate and the widest part was near this end. As the length increased, the brush end tapered and the widest part of the kernel approached the middle.

A study of the development in width shows that there was a rapid increase during the first three days, approximately 86 per cent of the growth in width being completed during this period. The daily means are given in Table II and illustrated graphically in Figure 5.

From the third to the eighth day after pollination, little change in measurement was recorded. Beginning with the eighth day, there was a second period of expansion up to the twelfth day, when maximum width was reached.

The width of a few kernels was noticeably affected by the heat from the thirteenth to the fifteenth day. On the second warm day, desiccation had progressed to the point of drawing in the side walls. The damp weather following the warm period did not re-establish the width of these kernels.

As the caryopses increased in dry matter toward the end of the developmental period, the width decreased. At the time the crop was considered ripe, the width was only 86.6 per cent of the twelfth-day average. With delayed harvesting, there was a further decrease in four days to 77.3 per cent of the maximum.

The figures indicating the mean daily trend in thickness are contained in Table II and graphically illustrated in Figure 5. Length and width increased most rapidly during the early part of the developmental stage. The increase in thickness, however, continued gradually up to the eleventh day, when 98.0 per cent of the final thickness was reached. Maximum thickness was recorded on the thirteenth day, with a sharp decline immediately following. The rapid falling off was in part due to kernels that were injured by heat on July 16. This was a very warm day and the sample gathered on the fourteenth day after pollination, July 17, showed the effect of the previous day's heat, as indicated by the measurements in Table II. A few of the kernels were distinctly flattened and the average thickness was lowered. While this affected some of the kernels, the majority had so nearly reached the ripe stage that the heat is thought not to have materially affected any of the results, as immature kernels were injured most severely. In addition to flattening, the kernels wrinkled and creased deeply and became firm and brittle. This is an indication that one might expect a decrease in yield if heat occurs during the early developmental stage. The more immature kernels in the lower whorls showed greater injury.

During the damp weather following the warm period, there was a tendency for the kernels with wrinkles to fill out, until finally most of them presented an appearance difficult to differentiate from natural ripening. The final appearance of a few kernels not thicker than the average during the first few days after pollination indicated that, in all probability, they did not recover from the premature desiccation.

Changes Within the Kernels

From the standpoint of knowing when to cut the crop for maximum yield and quality, it is desirable to understand the changes in green and dry weight, ash, and nitrogen content.

TABLE III

DAILY DETERMINATIONS OF GREEN AND DRY WEIGHT, ASH, AND NITROGEN OF GOPHER OAT KERNELS

Date	Days after pollination	Determinations on twenty primary kernels with hulls removed						Determinations on about fifty kernels with hulls removed		Stage of development of kernels
		Green weight	Dry matter	Dry matter per cent of maximum	Dry matter	Moisture	Weight of ash	Ash on dry matter basis	Dry weight used for nitrogen determinations	Nitrogen on dry matter basis	
		grams	grams	per cent	per cent	per cent	grams	per cent	grams	per cent	
July 4	1	0.0569	0.0129	3.2	22.67	77.23	0.0004	3.10	0.1055	6.94	
5	2	.0960	.0200	5.0	20.83	79.17	.0007	3.75	0.0750	9.33	
6	3	.1960	.0401	10.0	20.45	79.55	.0011	2.74	0.1950	4.24	
7	4	.2477	.0538	13.9	22.52	77.48	.0011	2.06	0.2450	3.77	
8	5	26.20	.0594	14.8	22.67	77.33	.0012	2.10	0.3712	4.38	
9	6	.3429	.0866	21.6	25.25	74.75	.0021	2.42	0.6995	4.20	Early milk
10	7	.4201	.1188	29.7	28.27	71.73	.0039	3.28	0.7417	4.00	
11	8	.5099	.1638	40.9	32.12	67.88	.0049	2.99	0.8685	3.88	First yellow color
12	9	.5877	.2152	53.8	36.61	63.39	.0059	2.74	0.8300	4.22	Late milk
13	10	.6217	.2428	60.7	39.05	60.95	.0079	3.25	1.4364	4.10	General yellow color
14	11	.6544	.2762	69.0	42.20	57.80	.0086	3.11	1.4774	2.40	Early dough
15	12	.6343	.2696	67.4	42.50	57.50	.0090	3.33	1.8464	2.60	
16	13	.6900	.3533	88.3	51.20	48.80	.0086	2.43	2.0544	2.70	Dough
17	14	.5952	.3484	87.1	58.53	41.47	.0090	2.58	1.5534	2.98	
18	15	.6632	.3882	97.0	58.53	41.47	.0089	2.29	1.8150	2.58	First ripe
19	16	.5697	.3793	94.8	66.57	33.43	.0094	2.47	1.5900	3.18	
20	17	.5464	.3963	99.0	72.52	27.48	.0094	2.37	1.5934	2.96	General ripe
21	18	.4937	.3949	98.7	79.98	20.02	.0094	2.39	2.2735	3.00	
22	19	.5206	.3994	100.0	76.71	23.29	.0094	2.36	1.8432	2.60	
24	20	.4633	.3702	92.5	79.90	20.10	.0095	2.56	2.1664	2.90	
24	21	0.4672	0.3668	91.7	78.51	21.49	0.0094	2.56	2.0172	2.56	

Green weight.—Each sample of twenty kernels was weighed immediately after the physical measurements were determined. The daily weights are given in Table III, column 2, and the trend is illustrated graphically in Figure 6. During the first eleven days, the green weight of twenty kernels increased rapidly, with an average daily increment of 0.0543 gram. The graph indicates that this was practically a straight-line increase. Maximum green weight was reached on the thirteenth day and after the fifteenth day there was a pronounced decline.

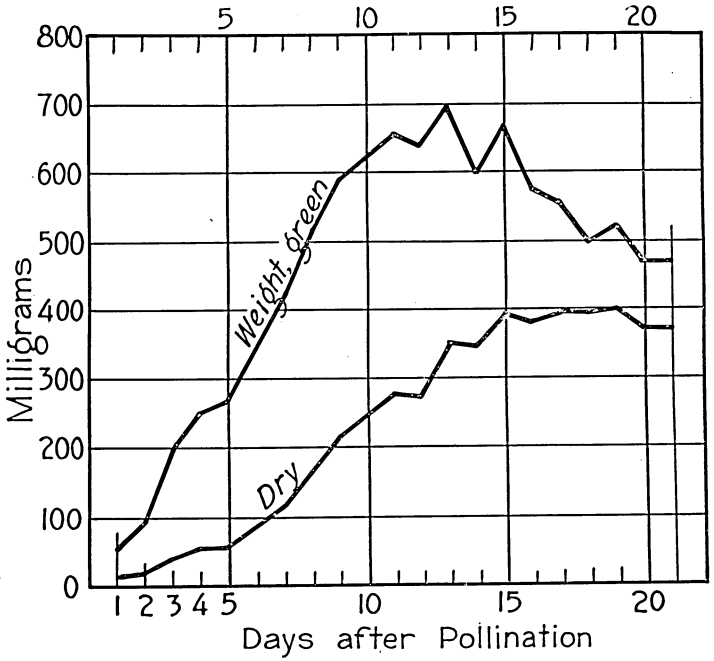

Fig. 6. Daily Green (Wet) and Dry Weights of Twenty Kernels After Removal of Hulls, from the Day After Pollination Until Maturity

Dry matter.—The actual dry matter content of the kernels increased uniformly up to the fifteenth day after pollination. At this time, twenty kernels, with the hulls removed, contained 0.3882 gram of dry matter. The final dry weight, on the nineteenth day, was 0.3994 gram. The actual dry weight should not be confused with the percentage of dry matter. During the ripening period, moisture was lost rapidly, and as a result the percentage of dry matter increased after the actual accumulation of dry matter ceased. The figures in Table III indicate this clearly. In column 3 the actual dry weights are given; in column 5, the percentage of dry matter for the same day. From the seventeenth to the eighteenth day, the actual amount of dry

matter decreased slightly, but the percentage increased from 72.52 to 79.98 on the eighteenth day. On the nineteenth day the dry matter content was 76.71 per cent; on the following days it was 79.9 and 78.51 per cent, respectively. The changes in green and dry weight are

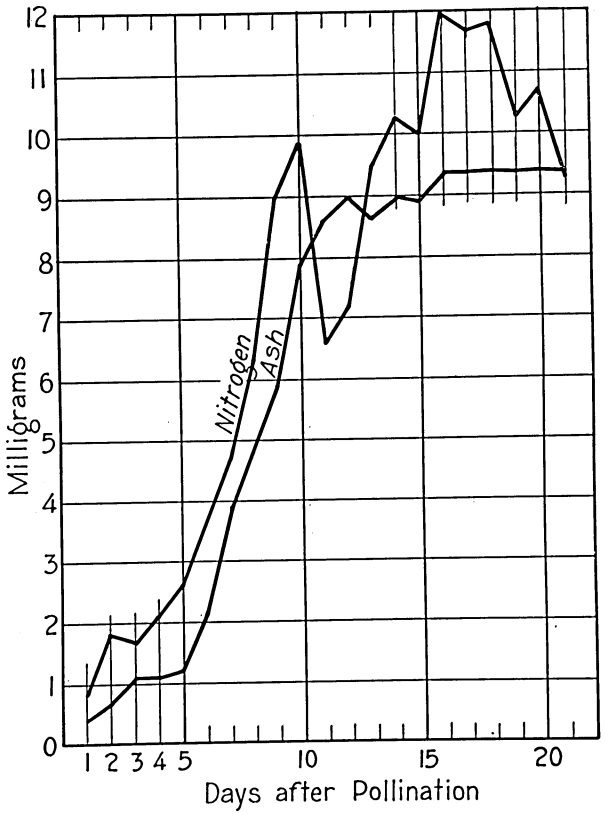

Fig. 7. Daily Weight of Nitrogen and Ash in Twenty Primary Kernels of Gopher Oats with the Hulls Removed, from the Day After Pollination Until Maturity

illustrated graphically in Figure 6. The increase in dry matter was slow during the first five days but rapid from the fifth to the fifteenth day. After the fifteenth day, when the first ripe kernels were noted within the group used in this study, the total dry matter content remained nearly constant up to the twentieth day, when there was a tendency to decrease 8.3 per cent of the maximum amount with delayed harvesting. Harlan (8) and Kedzie (17) found a similar, tho longer, trend in the increment of dry matter in barley and wheat.

Ash content.—Ash was stored slowly during the first five days and then very rapidly until the twelfth day. The daily content of twenty kernels with the hulls removed is given in Table III, column 7,

and graphed in Figure 7. On the fifth day there was 0.00125 gram in twenty kernels. This had increased to 0.0090 gram on the twelfth day, the increase per day being fairly uniform. There was a slight increase during the ripening period and no tendency for the amount of ash to decrease with delayed harvesting.

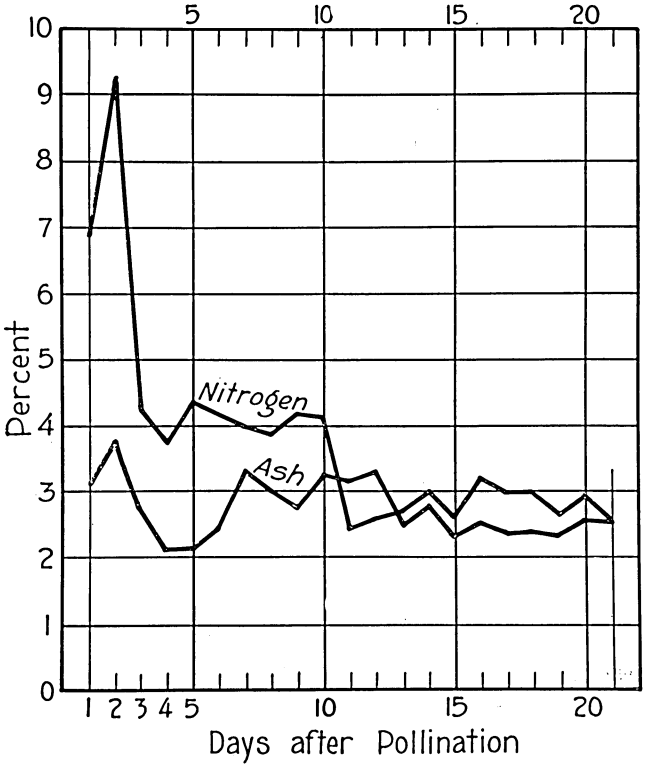

Fig. 8. Daily Change in Nitrogen and Ash Content Expressed in per Cent of Dry Matter

The proportion of ash expressed on a percentage basis was relatively high during the first few days after pollination, as illustrated graphically in Figure 8. The highest percentage was recorded on the second day. The proportion of ash remained high until the kernels reached the dough stage. There was 2.37 per cent of ash at the normal harvesting period.

Nitrogen content.—The problem of determining the total nitrogen in the first samples obtained was difficult. The dried kernels were extremely small and many were required for analysis. Each day's sample contained about fifty kernels, from which the hulls were removed at the time of analyzing. The weight of the air-dried kernels with

the hulls removed was ascertained and then the actual nitrogen in the given weight was determined. The weight of kernels with hulls removed is given in Table III, column 9. Fine sand was mixed with the samples before grinding and the nitrogen content was determined by the Kjeldahl method. The values given may be regarded only as close approximations, owing to the large error involved in making the chemical determinations on relatively small samples. The size of the samples increased from 0.075 gram in the first few days to 1.5934 grams when the kernels were mature.

The nitrogen percentage of each dry weight is given in column 10 and graphed in Figure 8. The air-dried sample two days after pollination contained 9.33 per cent of nitrogen and at the normal harvesting period, 2.96 per cent.

To determine the location of the line in Figure 7 that indicates the trend in nitrogen content, the dry weight of twenty kernels with the hulls removed was multiplied by the percentage of nitrogen in the larger sample for the respective day. The graph, therefore, represents the calculated content of nitrogen in twenty kernels. The actual quantity found in the first few days was only a fraction of the total amount laid down. The increase was very rapid and fairly regular from the first to the tenth day. From the thirteenth to the sixteenth day a further increase in nitrogen is indicated, and after this date some loss with delayed harvesting.

Relationship Between External and Internal Characters

A detailed study of the relationship between external appearance and internal development was not a part of this investigation but careful notes on the changes in the appearance of kernel and floral parts were recorded. These observations are given along with the laboratory determinations to illustrate the relationship between internal and external evidences of maturity. The following is a brief summary of the field notes and laboratory determinations. The laboratory data on which the summary is based are included in Tables II and III and illustrated in Figures 2 to 8.

One day after general pollination of the kernels used in this study and four days after pollination in the apical spikelet: Pollination incomplete in the lower whorl. No marked change in the size of the ovary since previous day.

Two days: Marked increases in physical measurements, in green weight, and in nitrogen and ash content. Time of maximum percentage of nitrogen and ash.

Three days: Very rapid increases in length, width, green and dry weight, and in ash content. Marked falling off in the percentage of nitrogen and ash.

Four days: Pollination incomplete in lower whorl. Rapid increase in length, thickness, green and dry weight, and in nitrogen content. Slow gains in width and in ash content. Low point in percentage of ash.

Five days: Pollination complete in all florets of lower whorl. First trace of milky color in the endosperm of kernels in middle whorl. Rapid increases in length and in nitrogen content. Slow gains in width, green and dry weight, and in ash content.

Six days: End of the period of rapid increase in length. Rapid gains continued in thickness, green and dry weight, and in nitrogen and ash content. Percentage of ash established as at maturity. Width not increasing.

Seven days: Slow increase in length. No change in width. Marked increases in thickness, green and dry weight, and in nitrogen and ash content.

Eight days: Marked increases in length, thickness, green and dry weight, and in nitrogen and ash content. First trace of yellow in the pericarp.

Nine days: Slow gain in length. Rapid gains in width, thickness, green and dry weight, and in nitrogen and ash content. Distinct yellowing of kernels. Pericarp could be peeled free from seed. Late milk stage.

Ten days: Slow gains in length and width. Rapid gains in thickness, green and dry weight, and in nitrogen and ash content. Last date on which there was a high percentage of nitrogen. First trace of yellow in the glumes of the apical spikelets.

Eleven days: Slow gains in length, thickness, and width. Rapid gains in green and dry weight and in ash content. Percentage of nitrogen established as at maturity. Early dough stage. Lower leaves browning off. A few kernels showed a distinct amber color.

Twelve days: No gains in length or thickness. Maximum width attained. Temporary decline in green and dry weight. Upper spikelets showing a straw color. The stems were also distinctly lighter in color.

Thirteen days: First decided appearance of ripening in spikelets. Maximum thickness and green weight. Gains in length and dry matter. Beginning of decline in width. Kernels in dough stage, most of them amber color.

Fourteen days: Decline in width, thickness, and green and dry weight. Slight gain in length. Some kernels shriveled by heat. Kernels of middle whorl in late to hard dough stage. Apical kernels ripe. Kernels of lower whorl in late milk stage.

Fifteen days: Maximum length reached. Rapid decline in green weight after this time with no material increase in dry matter. A

few of the glumes in the apical spikelets completely straw color with some of the glumes of spikelets in the middle whorl about half turned. First ripe kernels in middle whorl.

Sixteen days: Late to hard dough stage. Maximum nitrogen content with no material change in ash content after this date. A rather steady decline in physical measurements and green weight after this time. With the exception of an occasional light green glume, about 50 per cent of each glume surface of the spikelets used in this study was straw color.

Seventeen days: First noticeable hardening of lemma and palea. Ordinary harvesting period. Moisture content of primary kernels of the group studied, 27.48 per cent. A few of the kernels in the lower whorl still in dough stage. Slight increase in dry weight.

Eighteen days: Endosperm of all primary kernels mealy. Moisture content of the primary kernels of the group studied, 20.02 per cent. In the lower whorls, glume surface still 25 to 50 per cent green, the palea having a green edge.

Nineteen days: Maximum actual dry weight and a decline with further ripening after this date. About 95 per cent of the glume surfaces in the middle whorl straw color. Some green in lower whorl. Past usual cutting time. Kernels completely ripe. Moisture 23.29 per cent.

Twenty days: Declines in all physical measurements and actual green and dry weights. Moisture 20.10 per cent.

Twenty-one days: Slight changes.

Application of Daily Growth Study to Farm Practices

The time required for complete pollination within the panicle has a direct bearing upon the harvesting period. There was a tendency for later kernels to develop rapidly, but uneven ripening within the panicle was the rule. Ripening in the spikelets followed in the same order as pollination, from the apex downward. The yield and quality must be influenced by the filling and ripening of the kernels in the lower whorl.

It is apparent from the data in Tables II and III that the maximum physical size of the kernel was attained at about fifteen days after pollination and the dry matter content at this stage of development was within 3 per cent of the maximum. This was considered the end of the developmental period. Only a few of the usual indications of ripening were apparent at this time. The developmental stage was followed by a period of about four days during which the entire plant ripened rapidly and the actual weight of dry matter increased 3 per cent. During this period only slight increase in yield could be expected from delayed harvesting, but the appearance of the

threshed grain improved as the green faded out of the lemma and palea. There was an indication of a slight loss in total dry matter and nitrogen content with over-ripening.

The moisture content was reduced to about 20 per cent one day after the estimated usual time of harvesting. Considering that some rain fell on each of the two previous and the three following days, and that the sample, still wet with dew, was gathered before seven o'clock in the morning, the moisture percentage of the kernels during the last four days was low.

EFFECT ON GERMINATION OF IMMATURITY AND CONTROLLED LOW TEMPERATURES

The effect on germination of immaturity and controlled low temperatures was investigated at the same time as the study of kernel development.

Materials and Methods

Three varieties of oats were used in the study—Gopher, Banner, and Victory. The three were grown side by side in one of the variety test blocks at University Farm. The plots were 8 feet wide and 134 feet long. The oats were seeded with an ordinary drill on April 10. A border, consisting of two outside drill rows on each side and a one-foot swath at the ends, was removed before sampling. The plot of Gopher oats used in the study of daily development was included in the same group, altho seeded ten days later.

The soil and seasonal climatic conditions have been described. The details of precipitation and temperature are given in Table I.

Gopher oats was ripe on July 16, Victory on July 23, and Banner on July 22. Yields for the season and long-time averages are as follows: Gopher 1926, 34.1 bushels; 1921-27 average, 58.5 bushels. Victory, 1926, 39.2 bushels; 1921-27 average, 58.4 bushels. Banner, 1926, not included in variety trials. Gopher, 1926, average straw length 24 inches. Banner and Victory, 1926, average straw length 30 inches.

In the study of daily development, it was observed that actual dry matter content of the kernels was closely correlated with maturity. Therefore, to check the maturity of the samples, it was necessary to determine the dry matter content each day. Check samples of approximately ten representative panicles of each variety were used for this purpose. The procedure in each case was the same but the varieties were kept separate. After discarding the immature spikelets, as mentioned on page 11, thirty primary kernels were selected at random from the group. These were hulled, weighed immediately, dried for twenty-four hours at 204.8°F. (96°C.) and then re-weighed to determine

the dry matter content. After further drying, the sample was again weighed to check the accuracy of the first figure.

Technic of Exposure to Controlled Low Temperatures

Each day from July 8 to 23, samples for exposure to controlled temperatures were gathered in the morning, between six and seven o'clock. The equivalent of a large binder sheaf of each variety was harvested by pulling the oats at six distributed areas in the plot. With the roots attached, the plants of each variety were wrapped separately in a damp cloth before they were taken from the field.

In the laboratory, each large sheaf was spread out on a long bench and groups of heads were selected at random throughout the length of the bench to make up smaller sheaves. The large sheaf was thus split into seven smaller ones. Six of these were subjected to various freezing temperatures and the seventh was used as a check.

In addition to the eighteen small sheaves, three lots of Gopher oats growing in pots were subjected to controlled temperatures each day. After exposure in the low-temperature chamber the pots were reset in the field, where they had been placed at seeding time in the spring. The other samples were grouped together each day in two cotton bags with the checks included and hung to dry in an airy place. Altho the early samples contained a high percentage of moisture, they dried thoroly with few exceptions. Early in the fall, the samples were taken to the seedhouse and stored in metal boxes. After threshing in December, the oats were placed in paper envelopes and stored in metal boxes in the Seed Laboratory during the winter months.

The desired temperatures were obtained by using a Lipman artificial refrigeration plant, consisting of an insulated chamber lined with coils in which liquid ammonia vaporizes. After expansion, the gas is drawn back by a pump located outside the chamber and is compressed and liquefied before recirculating in the coils. Vaporizing the liquid ammonia in the coils reduces the temperature in the insulated chamber and by continued operation temperatures as low as —40°F. (—40°C.) can be obtained. Hildreth (1926) described the machine briefly.

The insulated chamber was enclosed in a small booth as a further precaution in maintaining the temperature. A thermograph, two minimum thermometers, and a fan were enclosed in the freezing chamber. The fan kept the cool air in rapid circulation.

The temperatures were maintained by Harvey thermo-regulators within a range of ±0.54°F. (±0.3°C.) when the machine was operating smoothly. The electric light bulb in the fan circuit burned out repeatedly on July 8, allowing the temperature to fall to 23°F. (—5°C.) on three occasions, in all, about fifteen minutes. The thermo-regulator was changed on July 18 and the temperature of 31°F. (—0.5°C.)

fell to 22° to 25°F. (—5.6° to —3.9°C.) for half an hour before being noticed. On July 19 a temperature control of 26°F. (—3.3°C.) was used for two hours instead of 29° and 27°F. (—1.7° and —2.7°C.).

The small sheaves were placed on wire shelves in the chamber with space between to allow free movement of air. Care was taken to prevent any of the material touching walls, pipes, or temperature control. A check on the time required to readjust the temperature after the doors had been opened showed that at each sixty-minute change of temperature and samples three to five minutes was required to cool off. In interpreting results, it should be remembered that this adjustment period formed part of the sixty minutes at any given temperature.

The treatments to which the samples were subjected have been grouped below according to severity. Equal numbers of samples of Gopher, Victory, and Banner oats were subjected to each treatment.

Group A. Cooled two hours at 35°F. (1.7°C.). Exposed one hour at 31°F. (—0.5°C.).

AA. No pre-cooling. Exposed one hour at 31°F. (—0.5°C.).

Group B. Cooled two hours at 35°F. (1.7°C.). Exposed one hour at 31°F. (—0.5°C.) and then an additional hour at 29°F. (—1.7°C.).

BB. No pre-cooling. Exposed one hour at 29°F. (—1.7°C.).

Group C. Cooled two hours at 35°F. (1.7°C.). Exposed one hour at 31°F. (—0.5°C.), one hour at 29°F. (—1.7°C.) and then an additional hour at 27°F. (—2.7°C.).

CC. No pre-cooling. Exposed one hour at 27°F. (—2.7°C.).

Group D. Check samples, neither cooled nor subjected to freezing temperatures. Dried with the other samples each day.

Group E. Conducted only on July 13. Cooled two hours at 35°F. 1.7°C.). Exposed one hour at 31 to 30°F. (—0.5 to —1.1°C.), and then two hours at 27°F. (—2.7°C.).

EE. No pre-cooling. Exposed two hours at 27°F. (—2.7°C.).

Groups AA, BB, CC, and EE were stored in the laboratory wrapped in a damp cloth while the other samples were cooled. They were therefore exposed to the low temperatures without any previous cooling.

The machine was in operation from 8 a.m. to 1 p.m. each day. Starting at 8 o'clock, the chamber was maintained at 35°F. (1.7°C.) for two hours with all the samples of groups A, B, and C in the chamber. The three pots of Gopher oats were also included. At 10 a.m. the temperature was reduced to 31°F. (—0.5°C.) and the samples in group AA were added to those in the chamber. One pot of Gopher oats and the samples in groups A and AA were removed at 11 o'clock. Simultaneously group BB was inserted and

the temperature was reduced to 29°F. (—1.7°C.). At 12 o'clock the second pot of Gopher oats and the samples in groups B and BB were removed. Group CC was immediately placed in the chamber and the temperature was reduced to 27°F. (—2.7°C.) and maintained for one hour. The last samples were removed at 1 p.m.

Groups E and EE consisted of samples subjected to temperatures slightly different from those previously mentioned and included only on July 13. Group E was pre-cooled for the usual two-hour period at 35°F. (1.7°C.) and exposed one hour at 30 to 31°F. (—1.1 to —0.5°C.). Group EE was not pre-cooled. Both groups were held at 27°F. (—2.7°C.) for two hours.

All samples exposed to the temperature of 31°F. (—0.5°C.) on any one day were in the cooling chamber together between the hours of 10 and 11 o'clock in the morning. All samples for the day reported exposed to 29°F. (—1.7°C.) were in the chamber from 11 o'clock until noon. The results for any one day as between varieties exposed at the same temperatures are, therefore, directly comparable.

After the samples were removed from the chamber, they were stored in the outer booth at a temperature ranging from 61° to 65°F. (16.1° to 18.3°C.) until the middle of the afternoon. Facilities were not available to duplicate the natural transitions in temperature of an autumn morning, but the test was probably more severe than field conditions.

The samples in Group C were subjected to what might be considered an early fall frost, being chilled for two hours at a temperature just above 32°F. (0°C.). They were then maintained at lowering temperatures of 31° F. (—0.5° C.), 29° F. (—1.7° C.), and 27° F. (—2.7° C.) for three hours. The change back to normal temperatures while protected from the sun also approached field conditions as nearly as possible.

Germination Tests

Laboratory germination tests were conducted by the State Seed Laboratory. All samples were germinated in duplicate for seven days before counting.

Field germination was tested by seeding 100 kernels in one of the variety trial plots in the spring of 1927 about a week after it was possible to work the land. The field reading was made between the third and fourth weeks and later germination, if any, was disregarded. Wright (1921) pointed out that in field germination tests the seedlings were counted and then pulled out at the end of about three weeks. Only an occasional weak sprout appeared after the first count.

Laboratory Germination of Samples Exposed to Controlled Low Temperatures

The first samples of Gopher oats subjected to temperatures ranging from 35°F. (1.7°C.) to 27°F. (—2.7°C.) were in the late milk to early dough stage. Samples were exposed daily from this time to complete maturity. A study of the laboratory germination during the first five-day period, July 8 to 12, as summarized in Table IV, indicates that the exposed samples germinated about as uniformly as the checks. The mean germination of the check samples, group D, line 1, was 93.4 per cent, as compared to a range in germination from 84.6 to 96.2 per cent for the exposed samples, groups A to CC inclusive, line 1. There is a noticeable difference between the average germination of group B, line 1, and the check sample, group D, line 1. The exposed sample, group B, line 1, had an 8.8 per cent lower germination than the average for the checks. The importance of this difference is minimized because the average germination of the sample receiving the same treatment and an additional hour at 27°F. (—2.7°C.) was 92.2 per cent, group C, line 1, and this germination is within 1.2 per cent of the check. The significance of this difference has been determined by Student's method. The odds that the low-germinating sample and the check are significantly different in germination are approximately 9.82:1. In the second five-day period, July 13 to 17, the mean germination of the checks, group D, line 3, was 97.4 per cent; that of the exposed samples, groups A to CC inclusive, line 3, ranged from 98.2 to 99.2 per cent. The differences in average germination between the first and second five-day periods indicate that lower germinating power in the early samples was due to immaturity. During the third five-day period, from July 19 to 23, there was no material change from the figures reported in the second period. Apparently the temperatures to which Gopher oats were exposed had no consistent effect on germination.

Samples of Victory oats were subjected to the controlled temperatures daily through the stages from early milk to complete maturity. Both Victory and Banner oats were less mature when the first samples were taken and had a lower germination than Gopher oats. The laboratory germination of the untreated samples of Victory oats indicates reduced viability during the milk stage. The mean germination of the check samples, group D, line 11, for the first five-day period, July 8 to 12, which included the milk stage, was 70.8 per cent. The exposed samples, groups A to CC inclusive, line 11, ranged from 72.8 to 85.4 per cent for the same period. During the second period, from July 13 to 17, the checks, group D, line 13, averaged 98.2 per cent germination, with a range of 91.5 to 95.8 per cent for the exposed samples,

groups A to CC inclusive, during the same period. The germination of the checks, group D, line 15, during the third period, from July 18 to 23, was 98.4 per cent, with the mean germination of the exposed samples, groups A to CC inclusive, ranging from 95.6 to 99.0.

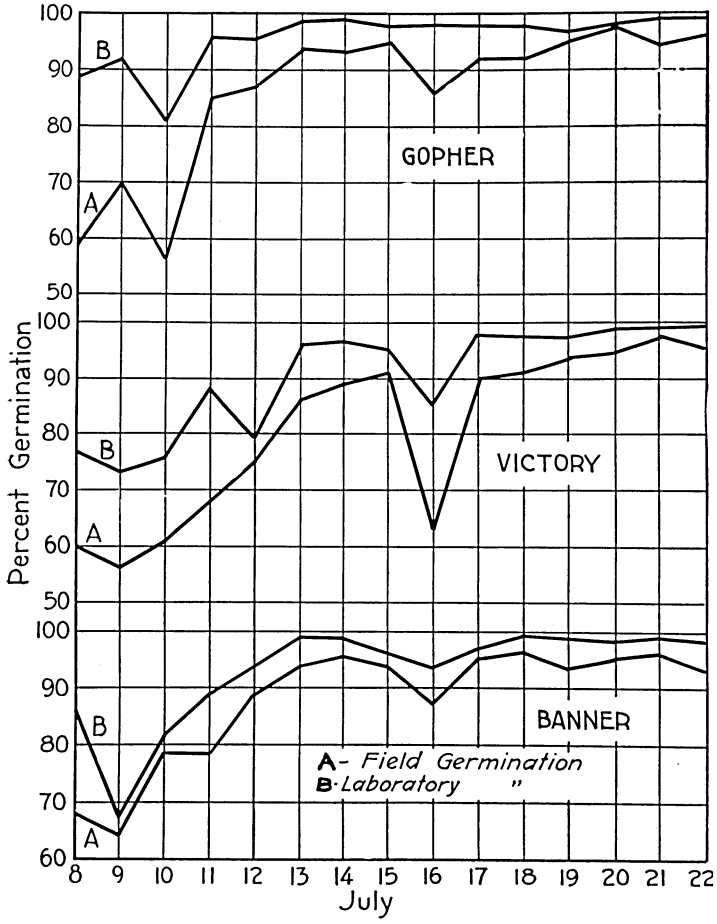

Fig. 9. Comparison of Mean Germination of Gopher, Victory, and Banner Oats
The upper line B in each group is the laboratory germination; the lower line A is the field germination.

Banner oats, also, was exposed to controlled temperatures daily from the early milk stage to complete maturity. There was considerable irregularity in the germination of the samples harvested during the milk stage. The mean germination of the checks, group D, line 21, during the first five-day period, from July 8 to 12, was 82.6 per cent and for the second period, line 23, 97.2. The difference in germination for the two periods is 14.6 per cent and is attributed to the

LABORATORY AND FIELD GERMINATION OF OATS HARVESTED AT DIFFERENT STAGES OF MATURITY AND SUBJECTED TO DIFFERENT TEMPERATURES

Variety and period	Method of making germination	Group A 2 hr. at 35°F. (1.7°C.) 1 hr. at 31°F. (−0.5°C.)	Group B 2 hr. at 35°F. (1.7°C.) 1 hr. at 31°F. (−0.5°C.) 1 hr. at 29°F. (−1.7°C.)	Group C 2 hr. at 35°F. (1.7°C.) 1 hr. at 31°F. (−0.5°C.) 1 hr. at 29°F. (−1.7°C.) 1 hr. at 27°F. (−2.7°C.)	Group AA 1 hr. at 31°F. (−0.5°C.)	Group BB 1 hr. at 29°F. (−1.7°C.)	Group CC 1 hr. at 27°F. (−2.7°C.)	Group D check no treatment	Line
Gopher		per cent	per cent	per cent	per cent	per cent	per cent	per cent	
First 5 days.....	Lab.	89.2	84.6	92.2	91.6	96.2	91.6	93.4	1
July 8-12	Field	71.0	65.6	72.0	70.8	74.4	75.8	74.2	2
Second 5 days.....	Lab.	99.2	98.5	98.6	98.2	98.5	98.4	97.4	3
July 13-17	Field	91.0	94.5	92.8	92.4	91.0	90.2	91.1	4
Third 5 days*.....	Lab.	97.2	99.0	97.6	99.2	99.0	97.0	97.6	5
July 18-23	Field	91.6	97.4	97.4	97.0	93.8	94.0	97.2	6
15-day average	Lab.	95.2	93.7	96.1	96.3	97.8	95.6	96.1	7
Probable error.....	....	±1.450	±2.024	±0.848	±1.133	±0.758	±0.897	±0.752	8
15-day average	Field	84.5	85.2	87.4	86.7	86.7	86.6	87.4	9
Probable error.....	....	±2.418	±3.202	±2.632	±2.528	±0.848	±1.886	±2.662	10
Victory									
First 5 days.....	Lab.	85.4	80.8	81.6	76.4	72.8	77.4	70.8	11
July 8-12	Field	68.6	67.4	66.6	61.6	63.4	60.4	66.4	12
Second 5 days.....	Lab.	95.8	91.5	93.2	95.4	92.5	95.2	98 2	13
July 13-17	Field	84.8	78.5	83.6	88.6	79.5	86.8	88.2	14
Third 5 days.....	Lab.	98.2	99.0	98.8	98.0	99.0	95.6	98.4	15
July 18-23	Field	95.4	96.4	93.0	95.6	96.8	84.2	92.4	16
15-day average	Lab.	93.1	90.3	91.2	89.9	87.7	89.4	89.7	17
Probable error.....	....	±1.261	±2.090	±1 989	±1.979	±3.235	±2.445	±3.026	18
15-day average	Field	82.9	80.9	81.0	81.9	79.9	75.2	82.3	19
Probable error.....	....	±2.479	±3.321	±3.434	±2.829	±3.534	±3.284	±2.681	20
Banner									
First 5 days.....	Lab.	78.6	90.0	80.6	84.0	81.0	85.6	82.6	21
July 8-12	Field	69.4	72.8	68.4	75.4	71.0	73.4	71.8	22
Second 5 days.....	Lab.	97.2	98.7	97.6	98.0	91.7	95.0	97.2	23
July 13-17	Field	95.6	97.7	92.2	92.0	86.2	93.2	91.0	24
Third 5 days.....	Lab.	98.8	98.2	98.2	98.6	98.8	99.0	99.2	25
July 18-23	Field	91.0	95.6	97.0	95.1	92.4	95.6	97.2	26
15-day average.....	Lab.	91.5	95.4	92.1	93.5	90.4	93.2	93.0	27
Probable error.....	....	±2.352	±1.336	±1.972	±1.824	±1.990	±1.472	±1.834	28
15-day average	Field	85.3	88.0	85.8	86.6	84.1	87.5	86.6	29
Probable error.....	....	±2.594	±2.717	±2.643	±2.001	±2.456	±2.294	±2.537	30

*July 21 omitted.

difference in maturity. The laboratory germination failed to bring out any conclusive evidence of injury due to the temperatures applied.

The groups of samples designated E and EE, on page 29, were subjected to more severe conditions. All three varieties were included in this test on July 13. The Victory and Banner samples contained 39.1 and 44.6 per cent dry matter, respectively, and the Gopher sample 66.1 per cent. The first two varieties were in the milk stage; the last was in the dough stage. The average germination of the exposed samples was similar to that of the checks.

The other changes in the temperature of the chamber mentioned on page 29 seemed to have no effect upon germination. Even with the temperature as low as 26°F. for two hours on July 19, no material effect could be detected.

Field Germination of Samples Exposed to Controlled Low Temperatures

A direct comparison of the laboratory and field germinations is made possible by the arrangement of the data in Table IV. Two lines are used to set forth the average germinations by five-day periods. In the upper line in each case are given the laboratory results and immediately below, in the respective columns, are the field germinations representing the same lots of grain.

In every average reported in Table IV the germination was lower in the field than in the laboratory. The differences were greater in the immature samples with the exception of Banner oats.

The first five-day mean germination of the check samples, group D, line 2, of Gopher oats for July 8 to 12, was 74.2 per cent. The range in the exposed samples, groups A to CC, line 2, was from 65.6 to 75.8 per cent for the same period. The low germination percentage of 65.6 for the sample, group B, line 2, as compared with another with a more severe treatment, group C, line 2, is similar to the results for the laboratory tests of the oats subjected to these treatments.

In the second five-day period, the germination of the checks, group D, line 4, was 91.1 per cent and the range in the exposed samples, groups A to CC, from 90.2 to 94.5. There was an increase of 16.9 per cent in the average germination for all groups for the second period over the first. The germination in the third period was still higher, the checks, group D, line 6, averaging 97.2, and the exposed samples, groups A to CC inclusive, line 6, varying from 91.6 to 97.4. These results indicate no appreciable injury as a result of being exposed to low temperatures. However, the germination was highest in the samples that were fully mature.

During the first five-day period the field germination of Victory oats was lower than that of Gopher or Banner. The average germi-

nation of the checks, group D, line 12, was 66.4 per cent and the range in the exposed samples, groups A to CC inclusive, line 12, from 60.4 to 68.6. The germination in the non-cooled groups, AA, BB, and CC, ranged from 60.4 to 63.4 per cent, line 12. This is one of the widest variations between checks and exposed samples. Even in this case some of the individual lots germinated higher than the checks. In the second five-day period the checks, group D, line 14, germinated 88.2 per cent and the exposed samples, groups A to CC inclusive, line 14, varied from 78.5 to 88.6 per cent. Groups B and BB, line 14, had a materially lower germination than the checks. Groups C and CC, line 14, with a more severe treatment, germinated nearly as high as the checks. It is again evident, altho with a different variety, that the germination was higher in the second five-day period than in the first, the average difference being 21.8 per cent. The checks, group D, line 16, germinated 92.4 per cent during the third five-day period, with a range of 84.2 to 96.8 per cent in the exposed samples. These samples were more nearly mature than those in the previous five-day period and had a higher average germination of 4.2 per cent.

The field germination of Banner oats during the early stages of development was similar to that of Gopher. The mean germination of the checks, group D, line 22, during the first five-day period, was 71.8 per cent and the range in the exposed samples for the same period from 68.4 to 75.4. In the second five-day period the checks, group D, line 24, averaged 91.0 per cent and the exposed samples varied from 86.2 to 97.7 per cent. During the third five-day period, when the oats were approaching maturity, the checks, group D, line 26, averaged 97.2 per cent, and the exposed samples ranged from 91 to 97 per cent. There was an increase of 19.2 per cent in the average germination in the second five-day period as compared with the average for the first period and a further increase of 6.2 per cent in the third period. There was no consistent evidence of freezing injury.

There was a distinct difference in the appearance of the seedlings produced by the different lots of seed. This was true for all varieties. The kernels harvested in the milk stage produced seedlings that were slender and pale green. They germinated quickly but less vigorously and grew less rapidly during the first few days. Kernels that were harvested in the dough stage produced seedlings that were dark green, broad-leaved, and vigorous. The differences were not so great at the end of ten days. These results agreed with the observations recorded for barley, corn, and wheat by Harlan (1922), Alberts (1926), and Crozier (1895).

Comparison of Fifteen-Day Average Germinations

The mean laboratory and field germinations for the fifteen-day period have been included in Table IV. Some means that show the widest variations have been selected to illustrate the lack of significant differences in germination between samples subjected to the various treatments. The mean germinations and differences are as follows:

Group	Line	Germination of exposed samples	Germination of checks	Difference in germination	Difference / Probable error
		per cent	per cent	per cent	
B	7	93.7±2.024	96.1±0.752	2.4±1.496	1.6
CC	19	75.2±3.284	82.3±2.681	7.1±1.650	4.3
BB	27	90.4±1.990	93.0±1.834	2.6±0.941	2.8
BB	29	84.1±2.456	86.6±2.537	2.5±2.131	1.1

The probable error of the difference was calculated by using the formula $\sqrt{Ea^2+Eb^2-2rabEaEb}$ where a and b represent the probable errors of the two germination percentages compared. The difference in germination between group CC, line 19, and the check amounts to 7.1±1.650 with odds of 267.1:1. This is a significant difference, according to the usual interpretation of statistical data. The importance of this difference is minimized, however, by the fact that similar samples, line 9, group C, exposed to more severe temperatures showed practically the same germination as the checks, line 19, group D. The other three differences, reported above, are not significant according to the usual interpretation of statistical data.

In Table V, which is a condensed summary of the averages as given in Table IV, percentages of laboratory and field germination have been grouped according to treatment before subjecting them to freezing temperatures and are given for each variety. The checks are included as a separate group. A direct comparison of average germinations is made possible by the method of exposing the samples. With the exception of one day, when only two samples were included, three different lots of each variety were exposed to different temperatures on each of fifteen days. The averages in Table V, therefore, were derived from the germination of forty-four samples, with the exception of the checks and the field germination of the non-cooled Victory oats. The averages reported in the check column are based on results from fifteen samples; the field germination of Victory oats represents an average of the results of forty-three samples instead of forty-four.

Samples of Gopher oats that were cooled and then subjected to various low temperatures had an average laboratory germination of 95.0±0.876 per cent. Similar samples that were not cooled before being subjected to the low temperatures averaged 96.5±0.543 per cent, while the checks, which were neither cooled nor exposed, averaged

96.1±0.752 per cent. The germination percentages for Banner and Victory samples showed similar close relationships. The differences between the mean germination of the samples subjected to the low temperatures and the checks are too small to be significant.

TABLE V

SUMMARY OF AVERAGE GERMINATIONS IN LABORATORY AND FIELD GIVEN IN TABLE IV

Method of germination and variety	Average germination of samples		
	Groups A. B, C, cooled and subjected to low temperatures	Groups AA, BB, CC not cooled but subjected to low temperatures	Group D, checks not cooled or subjected to low temperatures
	per cent	per cent	per cent
Laboratory			
Gopher	95.0±0.876	96.5±0.543	96.1±0.752
Victory	91.5±1.049	89.0±1.504	89.1±3.026
Banner	93.0±1.115	92.3±1.024	93.0±1.834
Field			
Gopher	85.7±1.599	86.6±1.088	87.4±2.662
Victory	81.6±1.794	79.0±1.864	82.3±2.681
Banner	86.3±1.530	86.0±1.303	86.6±2.537

If there had been a critical period in the development of the kernel, when it was more subject to injury from exposure to freezing temperatures, it should be evident in the comparison of the five-day averages in Table IV or the fifteen-day mean germinations in Table V. Similarly, if the degree of temperature or the duration of exposure was an influencing factor, it would be apparent by the same comparisons. There were no significant differences between the fifteen-day average germination percentages for the treated samples and the checks, but there was a pronounced increase in germination at the second and third five-day periods for each variety as compared with the average for the first period. This indicates that immaturity, instead of the low temperatures used, lowered the average germination.

Comparison of Laboratory and Field Germinations

The average laboratory germination of 264 exposed samples was 92.8 per cent as compared to 92.7 per cent for the 45 checks. The same 264 samples had an average germination in the field of 84.1 per cent as compared to 85.4 per cent for the 45 checks. When the laboratory germinations, 309 in number, are compared with those of the same lots tested in the field, germination is 8 per cent lower. As indicated in Figure 9, most of this difference can be accounted for by the spread between laboratory and field germination of immature samples. The differences in the germination at the five-day periods noted in Table IV, and the position of the lines in Figure 9, indicate that the widest variation between laboratory and field trials occurred during the early stages of kernel development. The average daily germination of the six samples exposed to low temperatures is graphed

in this figure. The daily dry-matter content of the samples and notes on the stage of maturity are indicated in Table VI.

TABLE VI

DRY MATTER CONTENT AND NOTES ON THE STAGES IN DEVELOPMENT OF SAMPLES EXPOSED TO CONTROLLED LOW TEMPERATURES

Date	Gopher		Victory		Banner	
	Dry matter	Stage of maturity	Dry matter	Stage of maturity	Dry matter	Stage of maturity
	per cent		per cent		per cent	
July 8	57.0	Milk to dough	34.9	Early milk	29.7	Early milk
9	55.5	Yellow kernels	33.8	.....	33.2	
10	62.0	First ripe	33.0	Milk	34.7	Milk
11	63.8	Some hard	35.1	Late milk	36.6	Late milk
12	....	.....	37.1	Early dough	39.7	Early dough
13	66.1	.....	39.1	.....	44.6	First yellow kernels
14	62.6	50 per cent hard	43.1	Dough	45.8	Dough
15	67.3	.....	43.6	Yellow kernels	53.4	Late dough
16	72.6	Ripe	47.2	Late dough	52.9	Some hard
17	86.6	Dry, mealy	....	First hard	57.9	
18	86.6	.....	63.1	.....	66.5	50 per cent hard
19	80.7	.....	59.6	.....	66.5	
20	87.4	.....	68.5	50 per cent hard	67.3	Some ripe
22	79 5	.....	69.9	.....	77.7	Ripe
23	84.9	.....	79.1	Ripe	80.9	Ripe, mealy

There was a marked spread between field and laboratory germinations of Gopher and Victory oats during the early stages of development. The general trend of the two lines, in both these varieties, indicates that the field germination approaches the laboratory germination as the oats near maturity. The field germination, however, remains slightly lower. The samples of Banner oats showed no material difference between laboratory and field germinations, but no explanation of this could be discovered. The sudden dips in the lines on July 9, 10, 12, and 16 do not coincide with the dates when the samples were subjected to lower than the desired low temperatures.

The spread between laboratory and field germinations indicated in Figure 9 emphasizes the inadequacy of the laboratory test to determine the true germinating value of immature oat samples.

Throughout the trials, the difference in the stages of maturity between Gopher, Victory, and Banner oats masked any variety differences that may have existed. The averages in Table V and the graphs in Figure 9 indicate that the trend of response was similar.

Correlation Between Dry Matter and Germination

The correlation between dry matter and germination was computed by using the averages graphed in Figure 9 and the dry matter data from Table VI.

There was a decided correlation between the quantity of dry matter in the sample at the time of harvest and the germination. This was

true in both laboratory and field germinations, but in the latter case the correlation was more pronounced, as indicated below.

	Gopher	Victory	Banner
Correlation between field germination and dry matter content	0.70±0.09	0.78±0.06	0.74±0.07
Correlation between laboratory germination and dry matter content	0.59±0.11	0.75±0.07	0.64±0.10

It is apparent from these data that there is a high correlation between field germination and percentage of dry matter. The above figures represent the correlation coefficient, altho the correlation ratio might have been used. Throughout the experiment, as indicated in Table VI, Gopher oats was the most mature and Victory the least, with Banner between. Owing to the earlier maturity and consequent higher dry matter content of Gopher oats, the correlation between dry matter and germination was lower for this variety than for Victory or Banner. It appears that dry matter, maturity, and germination are closely correlated.

EFFECT OF EXPOSURE TO LOW TEMPERATURES ON THE GREEN LEAVES AND STEMS OF IMMATURE OAT PLANTS

As a parallel study to the effect of frost on the viability of immature oat kernels, potted plants were used to study the effect of controlled low temperatures upon the plants themselves. The pots were exposed with the other samples to the regular temperatures listed on page 29 under groups A, B, and C, and kept from the sun in the booth surrounding the cooling chamber for about two hours before replacing them in the field.

The first pots of Gopher oats were exposed to the controlled low temperatures when the dry matter content of the kernels amounted to 26.6 per cent. According to the daily development study, this was the very early milk stage, six or seven days after pollination. Within twenty-four hours after being replaced in the field, they turned yellow and the stems began to break over. The stems of the plants exposed at 27°F. (−2.7°C.) crinkled much more freely and for a longer time than those exposed to 29°F. (−1.7°C.) and 31°F. (−0.5°C.). As the plants approached maturity, it was noticeable that fewer stems crinkled after being subjected to the low temperatures. From July 10 to 12, about 50 per cent of the plants exposed at 31°F. (−0.5°C.) and 29°F. (−1.7°C.) were injured in this way. During this time, the kernels were increasing in length and developing just enough starch to be considered in the milk stage. On the third day the kernels showed a dry matter content of 39 per cent, and only about 10 per cent of the culms of the plants exposed

at 31°F. (—0.5°C.) and 29°F. (—1.7°C.) broke over from this time until maturity. The percentage of culms that crinkled when exposed at 27°F. (—2.7°C.) decreased from 90 to 50 per cent during the first six days. By this time the dry matter in the kernels had reached 50 per cent and from then to maturity only about 10 per cent of the stems crinkled. There was more injury to stems exposed to the lower than to the higher temperatures.

A record was also kept of the effect on the color of the leaves and stems of exposure to freezing temperatures. The three temperatures had the same effect and no green color remained in the plants until July 17, at which time the kernels contained 58 per cent dry matter. The chlorophyll was destroyed and within a few days gave the plants the appearance of uniform ripening. It was estimated that on the above date the plants retained about 5 per cent of the green color. There was an increase in the proportion of green color retained by the plants from this time until natural ripening began. Exposure to a temperature of 31°F. (—0.5°C.) was as injurious in destroying the chlorophyll as exposure to 27°F. (—2.7°C.).

SUMMARY AND CONCLUSIONS

The daily growth of the Gopher oat kernel was studied from pollination to maturity, and samples of Gopher, Victory, and Banner oats in the early milk to ripe stages were exposed to controlled low temperatures at daily intervals.

The average period of flowering in panicles lasted about eight days, progressing from the apex downward. The kernels in the lowest whorl were still in the late dough stage when the apical kernels were ripe.

Growth in length was most rapid during the first six days and then more gradual until the maximum was reached on the fifteenth day. Width and thickness increased rapidly during the first ten days and reached a maximum before growth in length ceased.

Green weight increased rapidly for thirteen days; after the fifteenth day there was a pronounced decline. Dry weight increased more gradually than green weight until ripening began, on the fifteenth day. Increase in actual dry matter during the ripening period was 3 per cent of the maximum amount, and the loss when harvesting was delayed two days was 8.3 per cent.

Nitrogen increased rapidly during the first ten days and ash during the first twelve days. After this there was considerable fluctuation in the amount of nitrogen in twenty kernels, as indicated by the curve, and very slight differences in the amount of ash.

The developmental period of the kernels used in this study continued for fifteen days after pollination and was concluded when the

glumes of the apical spikelet became straw color. General ripening occurred in two days and was completed in four days, during which time the lemma and palea took on a uniform straw color and the moisture decreased from 41.47 to about 21 per cent.

Controlled temperatures ranging from 31° to 27°F. (—0.5° to —2.7°C.), extending over periods of from one to three hours, had no apparent effect on germination. This was true whether the samples were cooled for two hours before being exposed to low temperatures or were placed directly in the chamber without pre-cooling.

The average laboratory germination increased materially and the field germination to a still greater extent with the accumulation of dry matter in the kernels.

The average germination was higher in the laboratory than in the field. The laboratory germination of immature samples, with few exceptions, was relatively high and not a reliable indication of what results might be in the field.

The average laboratory germination of mature samples was always slightly higher than the field test, but was a reliable index of field germination.

The field germination of immature kernels was low and the seedlings lacked vigor.

During the developmental period, a temperature of 31°F. for one hour destroyed most of the green color in the plants of Gopher oats.

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